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Design of compact polarized neutron imaging system for accelerator based small neutron sources

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Abstract

Recently, compact neutron sources have been developed consisting of a small proton accelerator, a Be-target and a moderator, which can be installed in an experimental room. These sources have a possibility of various industrial applications because of their compactness. One of the applications is the polarized neutron imaging system. The system consists of neutron bender, polarizer, spin rotator, sample table, second spin rotator, spin analyzer and 2D-position sensitive detector. Since the neutron source is small and the imaging system should be installed near the moderator, the bender and polarizer have to be properly designed to have relatively wide acceptance angle for the incident beam. In the present study, the design and estimated results of such imaging system for will be presented.

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Keywords: Compact Neutron Source, Polarized Neutron, Neutron Bender

1. Introduction

Polarized neutron imaging is a technique based on spin handling technique, which enables us to non-destructive analysis of magnetic field in magnetic material. The polarized neutron imaging system requires a polarizer, two spin rotators upstream and downstream of the sample, a spin analyzer and a position sensitive detector. By analyzing 3×3 spin transfer matrix of the sample, it is possible to derive magnetic field direction and strength.

Although installation such system to accelerator driven neutron sources may have some problems, such as spin rotator applicable to pulsed neutrons, polarization of neutrons in a limited area, the combination of

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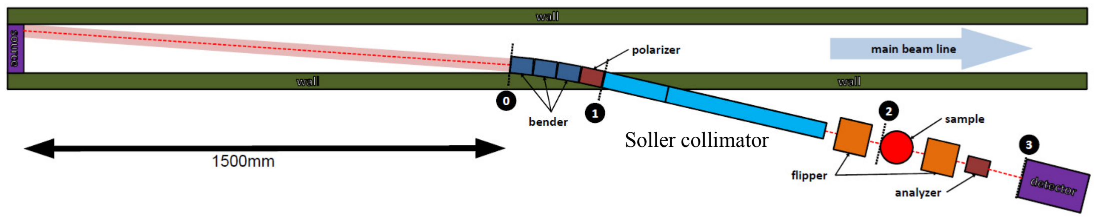

Fig. 1. The arrangement of the polarized beam line.

polarized imaging system and compact neutron source is useful for its compactness, low cost and easy operation.

In the present study, a polarized neutron beam line for polarized imaging is designed for Riken Accelerator-driven Neutron Source (RANS). Since the main neutron beam line of RANS is situated in the line of the incident 7 MeV-proton beam, the neutron beam contains large amount of fast neutrons with the energy up to several MeV. Since the neutrons with the energy higher than thermal energy may cause undesirable effects in the measurements, we designed the polarized beam line outside from the original beam line. In the present report, the results of Monte-Carlo simulation are presented.

2. Simulation and Results

The schematic view of the arrangement for the polarized imaging system is shown in Fig. 1. There are three neutron benders consisting of 50 pieces of 3Q-supermirrors, whose critical angle is three times as large as that of a Ni-mirror, upstream of polarizer. The benders are located at the position 1500 mm-distant from the moderator surface, and see the opposite side of the moderator surface in order to increase the bent angle of the polarized beam. After the benders, the polarizer consisting of 50 pieces of 3Q-polaizing supermirrors (50 mm (h) × 70 mm (h) × 0.5 mm (t)), is held in magnetic field of several hundred gauss. Nominal incident angle of the neutron beam to the bender is 1/70 radian. Since the length of each supermirror (both polarizing and non-polarizing) is 70 mm, the benders cover beam cross section of 50 mm (width) × 50 mm (length).

At the exit of the polarizer, Soller collimators for horizontal (200 mm-long) and vertical (500 mm-

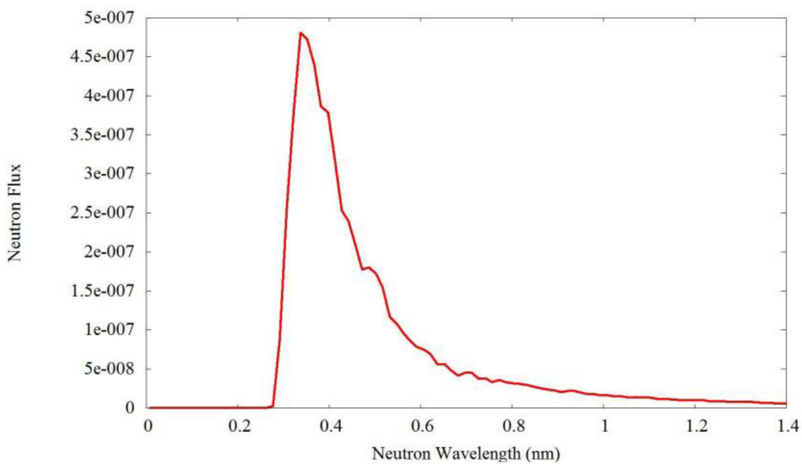

Fig. 2. Time of flight spectrum at the position 2.

long) direction is placed to eliminate the divergent neutrons, and to improve the polarization of the neutron beam. In both Soller collimators, plates made of neutron absorbing material are aligned with the gap of 5 mm. After the collimators two spin rotators before and after the sample, spin analyzer and the 2D-detector are situated. The spin analyzer consists of a set of 50 pieces of 3Q-polarizing supermirror, having anti-transmission layer behind the supermirror.

Simulations were performed using McStas V2.0 with the arrangement shown in Fig. 1. Since we are interested in low energy neutrons, neuron energy distribution in the source is assumed as Maxwellian.

Fig. 2 shows time of flight spectrum at the sample position. Horizontal and vertical axes represent neutron wavelength and neutron intensity, respectively. Intensity peak situated at about 0.3 nm of neutron wavelength, is as expected from the critical wavelength of supermirrors in the polarizer and the incident angle of 1/70 rad.

Estimated neutron polarization at the position 1, 2, and 3 in Fig. 1 are 0.75, 0.97 and 0.99. Low polarization at position 1 is due to the contamination of unpolarized neutrons because of wide divergent angle of incident neutrons. Since these unpolarized neutrons do not hit the polarizing supermirrors, the direction of unpolaized neutrons is different from that of polarized neutrons. The horizontal beam collimator just after the polarizer removes such unpolarized neutrons.

In addition, since in vertical direction there is no collimation of neutron beam, then to take clear image vertical neutron collimator should be employed before the sample.

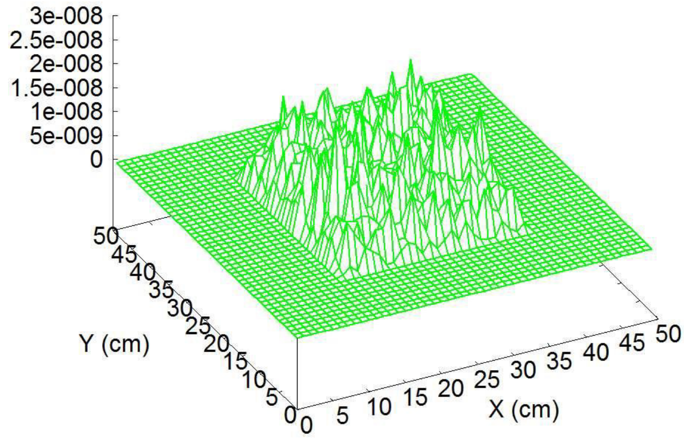

Fig. 3. Neutron distribution at the sample position.

Owing to such collimators, the spatial beam distribution at the sample position 2 in Fig. 1 is shown in Fig. 3. Neutron intensity is represented with z-position, and the horizontal and vertical axes stand for horizontal and vertical position, respectively. Although the intensity contains relatively large statistical error, almost flat distribution within 5 cm × 5 cm area is achieved.

The role of spin-rotators is to rotate neutron spin to desired direction. Before the sample, it fixes the spin direction of incident neutrons. After the sample, it rotates neutron spin so as to extract the spin component of definite (x, y, or z) direction, with the help of spin analyzer.

The spin analyzer reflects neutrons having the spin parallel to the magnetic field as well as the spin polarizer. In addition, it absorbs those having anti-parallel spin, with the help of absorbing layers deposited behind the supermirror.

3. Conclusion

We have designed a polarizing neutron imaging system for RANS, which has 5 cm × 5 cm area and neutrons with wavelength longer than 0.3 nm. By using Soller collimators, neutron divergence is limited and polarization of neutron beam incident to the sample keeps high, over 0.97. These properties may enable us to perform clear time-resolved polarizing neutron radiography.